Competency 2.1 **Waste management personnel shall demonstrate a working level knowledge of:**

- **29 CFR 1910.96**, ***Ionizing Radiation***
- **29 CFR 1910.97**, ***NonIonizing Radiation***
- **Department of Energy (DOE) Order 5480.11*, Radiation Protection for Occupational Workers***

1. SUPPORTING KNOWLEDGE AND/OR SKILLS

a. Compare and contrast the rem and other dose units.

b. Given appropriate data, classify an area as either a "restricted area" or an "unrestricted area" and state the reasons for the classification.

c. Discuss the requirements related to the exposure of individuals to radiation in restricted areas; include any applicable dose limits.

d. Discuss the requirements related to the exposure of individuals to airborne radioactive materials; include any applicable precautionary measures and personal monitoring requirements.

e. Discuss the requirements for posting the various types of radiation areas; include the requirements for exceptions to the posting requirements.

f. Discuss the requirements for exemptions for radioactive materials packaged for shipment.

g. Discuss the requirements related to notification of incidents.

h. Compare and contrast the terms "nonionizing radiation" and "ionizing radiation."

2. SUMMARY

Briefly, the rem is the unit of radiation dose equivalent. It is found by multiplying the absorbed dose in rads by the quality factor(^{Q})for the radiation in question. It is meant to be a measure of biological damage since different radiations can cause various damage for the same amount of energy absorbed per unit mass. The rem is appropriately used for low doses of radiation delivered at low dose rates, which describes most occupational exposure situations.

Exposure (X)

- Basic concept - Describes an x-ray or gamma-ray radiation field. It is a measure of the amount of ionization produced in air by x-rays or gamma rays.
- The conventional unit is the roentgen (R). In the international system (SI) of units, the coulomb/kilogram (C/kg) is substituted for the roentgen. One roentgen = 2.58 x 10^{-4} C/kg.
- The quantity exposure is only defined in air. It would be incorrect to say, "my dose was one roentgen" because the use of the roentgen indicates that reference is being made to the quantity exposure - a quantity not defined for human tissue.
- This quantity is considered outmoded by the International Commission on Radiation Units and Measurements (ICRU).

Absorbed Dose (D)

- Basic concept - Amount of energy absorbed per unit mass in the medium of interest.
- The conventional and SI units are the rad (no abbreviation) and the gray (Gy), respectively.
- Unit conversions: 1 Gy = 100 rad
1 Gy = 1 joule/kilogram (J/kg)
1 rad = 100 ergs/gram
- The quantity is not limited to photon radiations; it applies to all types of ionizing radiation.
- The quantity is not restricted to air, but is applicable to all types of material (air, water, human tissue, etc.).

Dose Equivalent (H)

- Basic concept - Has no precise or exact meaning. It is an administrative concept used for the purposes of radiation protection and is subject to change. It is only meant to apply at those doses commonly encountered in the field of radiation protection (in other words, it does not apply to large acute doses and accident situations). It is related to the amount of biological damage to a person from a given dose of radiation.

- The conventional unit is the rem (no abbreviation); the SI unit is the sievert (Sv).
- Unit conversions: 1 Sv = 100 rem
  1 Sv = 1 J/kg
- The quantity applies to all types of ionizing radiation.
- The quantity only applies to living humans.
- The dose equivalent (H) is the product of the absorbed dose (D) and the quality factor (Q); therefore,

$$H = D \times Q$$

Quality Factor (Q)

The quality factor (Q) relates the absorbed dose received by a worker to the dose equivalent. It only applies to chronic, low-level doses. Consider two individuals who receive the same absorbed dose (one worker from gamma rays, the other from neutrons). The biological damage (or risk) will be greater from the neutron dose. Regulatory controls are put in place to limit the risk, and some means must be used to take into account the different risks associated with different types of radiation, (^{Q}) is used for this purpose. Each type of radiation is assigned a quality factor based upon its potential to cause biological damage. The absorbed dose can then be multiplied by Q to calculate the dose equivalent. Typical quality factors for various radiation types are shown in the following table.

Radiation Type	Quality Factor
Gamma	1
X-ray	1
Beta	1
Neutrons $\leq$ 10 keV	3
Neutrons > 10 keV	10
Alpha	20

To minimize exposures to personnel from sources of ionizing radiation and any corresponding health effects, DOE places a strong emphasis on the concept of ALARA--an acronym standing for As Low As Reasonably Achievable. The ALARA philosophy is the cornerstone in a radiation protection program (RPP) for avoiding unnecessary doses and achieving the lowest radiation exposures to occupational workers and the general public as possible, taking into account economic, technological, and societal factors.

ALARA can be achieved in a variety of ways. Where internal doses are possible, good work practices should be encouraged and followed. These include:

- Refraining from eating, drinking, chewing, and smoking around radioactive materials.
- Wearing protective clothing.
- Performing adequate radiation monitoring before leaving an area.
- Washing hands before taking breaks or leaving the work site.

The above practices and others can go a long way towards reducing the inhalation or ingestion of radioactive materials into the body. For external radiation hazards, the previously mentioned radiation safety tenets of time, distance, and shielding are major exposure-reducing controls. Administrative controls, such as the use of radiation work permits (RWPs) and allowable job dose levels, are an essential ingredient in an ALARA program.

A variety of radiations are frequently encountered at DOE facilities. These radiations can be classified into two broad categories, ionizing and nonionizing. **Ionizing** radiation are those radiations that possess sufficient energy to eject electrons from neutral atoms. They include alpha particles, beta particles , gamma rays, x-rays, and neutrons. **Nonionizing** radiations can excite electrons to higher energy states but do not possess sufficient energy to eject electrons from the atom. Examples of nonionizing radiations include ultraviolet, visible, and infrared light, microwave and radio, power frequencies, radar, and laser light. Both ionizing and nonionizing radiations pose potential health hazards in the workplace. Radiological controls and practices should be tailored to the facility and the specific radiation hazard(s).

29 CFR 1910.96, *Ionizing Radiation*, are the Occupational Safety and Health Administration's (OSHA) regulations pertaining to ionizing radiation. These regulations, however, are outdated and are only mandatory as a matter of policy (see DOE Order 5480.4, *Environmental Protection, Safety and Health Protection Standards)*. 10 CFR 835, *Occupational Radiation Protection,* is much more recent and compliance is mandatory. There are some important differences between the two sets of regulations.

For example, the terms "restricted area" and "unrestricted area" are outdated terms. They appear in the OSHA regulations, but not in 10 CFR 835, which defines the following:

- <u>Controlled area</u> is any area to which access is managed in order to protect individuals from exposure to radiation and/or radioactive material. Individuals who enter only the controlled area without entering radiological areas are not expected to receive a total effective dose equivalent of more than 100 mrem (0.001 Sv) in a year.

- Radiological area, in accordance with 10 CFR 835.603, is any area within a controlled area that must be posted as a:
  - Radiation area
  - High radiation area,
  - Very high radiation area
  - Contamination area
  - High contamination area
  - Airborne radioactivity area

Again, the requirements for airborne radioactive material in the OSHA regulations are outdated, and appear in different form in 10 CFR 835. According to 10 CFR 835," airborne radioactive material" or "airborne radioactivity" means radioactive material in any chemical or physical form that is dissolved, mixed, suspended, or otherwise entrained in air. An airborne activity area means any area where the measured concentration of airborne radioactivity, above natural background, exceeds, or is likely to exceed, 10% of the derived air concentration (DAC) values listed in the appendices to 10 CFR 835. A DAC is that concentration of a radioactive material in air that, if breathed by Reference Man for 2,000 hours, would result in an intake of one annual limit on intake (ALI). The ALI is the quantity of a radioactive material taken into the body that would result in a committed effective dose equivalent (CEDE) of 5 rem per year or a committed dose equivalent (CDE) of 50 rem per year to any organ or tissue.

So, these requirements mean that DOE facilities must:

- Determine if radioactive materials are or can become airborne.
- Determine what radioactive materials are involved.
- Measure the concentration of the material in air.
- Look up the DAC values.
- Post the area as an "airborne radioactivity area" if the airborne concentration exceeds 10% of the DAC value.

10 CFR 835 also states that the DAC values shall be used in the control of occupational exposures to airborne radioactive material.

10 CFR 835 stipulates additional requirements for monitoring individuals for intakes of radioactive materials and requirements for air sampling. Bioassay data must be used to assess intakes of radioactive material unless air sampling results can be shown to be more accurate. Bioassay is required for radiological workers who are likely to receive 100 mrem or more CEDE and/or 5 rem or more CDE to any organ or tissue from all intakes during a year. Additional requirements are listed for declared pregnant workers, minors, and members of the public.

Air sampling is required by 10 CFR 835 if an individual is likely to receive an annual intake of 2% or more of the specified ALI values. Real time air monitoring using continuous air monitors (CAMs) shall be performed if an individual occupying the area is likely to be exposed to an airborne concentration greater than one DAC.

Perhaps one of the biggest changes from the OSHA regulations and the newer requirements of 10 CFR 835 has to do with summing both internal and external exposures. The dosimetry system in place at the time the OSHA regulations were written did not allow for summing internal and external exposures for an assessment of total risk to the individual. These exposures were assessed independently. For example, at that time, respirators were encouraged to be worn just about anytime there was an airborne concentration. Now that external exposures must also be considered, there are times when it is most prudent to enter an airborne radioactivity area without a respirator when the respirator would increase the amount of time in, and therefore external exposure from the airborne activity. This new way of thinking has been difficult for many workers to accept.

The posting requirements have changed from the OSHA requirements and 10 CFR 835. According to 10 CFR 835, the following areas need to be posted:

- A controlled area.
- Radiological areas.
- Radiation area where an individual could receive a deep dose equivalent of 5 mrem in an hour.
- High-radiation area where an individual could receive a deep dose equivalent of 100 mrem in an hour.
- Very high-radiation area where an individual could receive an absorbed dose of 500 rad in 1 hour.
- Airborne radioactivity area where the airborne concentration of a radionuclide is greater than 10% of the DAC.
- Contamination area where the contamination values are greater than (but less than 100 times than) the values listed in Appendix D of 10 CFR 835.
- High-contamination area where the contamination values are greater than 100 times the values listed in Appendix D of 10 CFR 835.

According to DOE Notice 441.1, *Radiological Protection for DOE Activities*, the following areas need to be posted:

- Radiological materials areas (RMAs).

The OSHA regulations specifically mention some exemptions from posting RMAs. These exemptions are not listed in 10 CFR 835; however, the exemptions appear in DOE N 441.1, which supersedes DOE Order 5480.11, *Radiation Protection for Occupational Workers*. The following are exempted from posting:

- Areas containing 10 or fewer sealed radioactive sources with activities below the accountability criteria in Attachment 1 of DOE N 441.1.
- Areas containing only radioactive materials packaged for shipment and labeled per Department of Transportation (DOT) regulations or corresponding DOE directives and expected to enter into transportation in the immediate future.
- Areas under continuous observation and control of an individual knowledgeable of and empowered to implement required access control measures.
- Areas containing radioactive materials in quantities below the site, or facility-specified posting threshold. This threshold shall be established at a level below that which is likely to cause any individual to receive a total effective dose equivalent in excess of 100 mrem in a year.

10 CFR 835 does not contain specific requirements for occurrence reporting or notification of incidents. There is, however, a DOE Order that addresses this issue. DOE Order 232.1, *Occurrence Reporting and Processing of Operations Information*, outlines the requirements for occurrence reporting. Briefly, this Order requires that facility staff and operators ensure that appropriate immediate response(s) are taken after an incident and that the facility manager is notified. The facility manager shall perform categorization and notification of emergencies, prepare written reports, and notify the DOE facility representative. The DOE facility representative notifies the head of the field element and notifies the DOE program manager of unresolved actions or determinations. The DOE program manager shall notify the cognizant secretarial officer. The contractor is required to establish an occurrence reporting program.

Part of the OSHA regulations mentioned in the above competency pertain to nonionizing radiation. As mentioned earlier, these regulations are only mandatory at DOE facilities as a matter of policy. There are a couple of other standards pertaining to nonionizing radiation that are mandatory as a matter of policy which are more current and much more detailed than the OSHA standards. These two standards are: ANSI Standard Z136.1-1980, *Safe Use of Lasers*, and ANSI Standard C95.1-1982, *Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 300 kHz to 100 GHz.*

3. SELF-STUDY SCENARIOS/ACTIVITIES AND SOLUTIONS

Scenario

Some 55-gallon drums of waste are being stored in a waste storage building at a DOE facility. The drums contain mostly uranium-238 (U-238) oxide ($U_3 O_8$). Workers routinely enter the area to monitor the drums, ship out drums, receive more drums, perform inventory, etc. The potential exists for leaking drums and airborne radioactive material in the building. Preliminary air sampling results indicate a concentration of 4 E-11 Ci/ml.

Activity 1

Considering the U-238 only, at what level would the area need to be identified as an airborne activity area? Based on the preliminary air sampling results, does the area need to be posted as an airborne radioactivity area? (The DAC values are listed in Appendix A of 10 CFR 835. First, a determination of the pulmonary clearance class has to be made. Appendix B contains the clearance classes for various compounds.)

Activity 2

At what level would air sampling be required by 10 CFR 835? (**NOTE:** ALI = 4 E-2   Ci)

Assuming that the average time spent by an employee performing monitoring, shipping, receiving, inventory, etc., is about 160 hours in a year and the breathing rate for Reference Man is 1.2 E6 ml/hr, is air sampling required?

Activity 3

Is real-time monitoring required?

Activity 1, Solution
(Any reasonable paraphrase of the following is acceptable.)

Per 10 CFR 835, the area would have to be identified as an airborne activity area where the measured activity is likely to exceed 10% of the DAC for U-238 oxide. U_3O_8 is assigned clearance class "Y." The listed DAC for U-238, Class Y is 2 E-11 Ci/ml, 10% of this value is 2 E-12 Ci/ml.

Yes, the area must be designated as an airborne activity area since preliminary air sampling results indicate a U-238 concentration of 4 E-11 Ci/ml, which is greater than 2 E-12 Ci/ml, the level at which the area must be posted.

Activity 2, Solution
(Any reasonable paraphrase of the following is acceptable.)

Per 10 CFR 835, air sampling is required if an individual is likely to receive an annual intake of 2% of the ALI for U-238. The ALI is 4 E-2 Ci, and 2% of that value is 8 E-4 Ci.

To calculate a potential intake, multiply the concentration by the average time spent in the area by the breathing rate for Reference Man.

(4 E -11 Ci/ml) *x* (160 hrs/yr) *x* (1.2 E6 ml/hr) = **8 E-3 Ci/yr**

Air sampling is required since the estimated annual intake is about 2% of the ALI.

Activity 3, Solution
(Any reasonable paraphrase of the following is acceptable.)

Real-time monitoring is required since the concentration of U-238 in the building (4 E-11 Ci/ml) is greater than one DAC (2 E-11 Ci/ml).

4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

Readings

- 10 CFR 835, *Occupational Radiation Protection*.
- DOE Order 5480.4, *Environment Protection, Safety and Health Protection Standards*.
- DOE N 441.1, *Radiological Protection for DOE Activities*.
- DOE Order 232.1, *Occurrence Reporting and Processing of Operations Information*.
- ANSI Z136.1-1980, *Safe Use of Lasers*.
- ANSI C95.1-1982, *Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 300 KH2 to 1006H2*.

<u>*Courses*</u>

- *Nuclear Physics/Radiation Monitoring* -- DOE.
- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Fundamental Radiological Control*, sponsored by the Office of Defense Programs, DOE.
- *Applied Health Physics* -- Oak Ridge Institute for Science and Education.
- *Health Physics for the Industrial Hygienist* -- Oak Ridge Institute for Science and Education.
- *Radiological Worker Training* -- DOE-EH.
- *Radiological Control Technician Training* --DOE-EH.
- *Safe Use of Radionuclides* -- Oak Ridge Institute for Science and Education.